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TROPICAL CYCLONE WIND PROBABILITY FORECASTING FOR THE EASTERN NORTH PACIFIC (EPWINDP)

Prepared By:

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Science Applications Inc.
Monterey, CA 93940

Contract No. N00228-81-C-H361

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development of a model to estimate 30 and 50 kt wind probabilities from tropical cyclone forecasts is described.

The model is based on position forecast errors, which are used to determine the probability of a cyclone occupying a particular geographical position, and on wind profile errors. Wind profile errors consist of errors in the forecast maximum wind and errors in the forecast radius of 30 and 50 kt winds. The profile errors are used to estimate

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Block 20, Abstract, continued.

the probability of 30 and 50 kt winds occurring at a point, given that the tropical cyclone occupies a particular position. These position and wind probability elements are combined by using an assumption of independence which was supported by correlation coefficients in an earlier work.

The model, which includes features of the earlier strike probability model and an Atlantic Ocean wind probability model, is tested on independent data. Test results are shown to illustrate good agreement between forecast probability and the frequency of occurrence of 30 and 50 kt winds.

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TROPICAL CYCLONE WIND PROBABILITY FORECASTING

FOR THE EASTERN NORTH PACIFIC (EPWINDP)

1.0 Introduction

The concepts and development of tropical cyclone wind probability forecasting for the eastern North Pacific follow closely those originally presented by Jarrell[1] (1981) for the western North Pacific. This is the third in a series of wind probability forecasting program reports covering different ocean basin areas. The initial report on the western North Pacific was followed by a similar report on the western North Atlantic (Jarrell[2], 1981). This report and the two previous are based upon an extension of the concepts developed for tropical cyclone strike probability forecasting (Jarrell[3], 1978). As these concepts have been previously presented and the programs are presently operational, a redevelopment of the concepts will not be presented in this report. A brief summary will be presented as a background for the new reader. If more detailed information is desired the reader is referred to the above mentioned documents. Differences between the development of eastern Pacific tropical

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[1]Jarrell, J.D., 1981: Tropical Cyclone Wind Probability Forecasting (WINDP), NAVENVPREDRSCHFAC Contractor Report CR 8-1-03.

[2]Jarrell, J.D., 1981: Atlantic Hurricane Wind Probability Forecasting (WINDP), NAVENVPREDRSCHFAC Contractor Report CR 81-04.

[3]Jarrell, J.D., 1978: Tropical Cyclone Strike Probability Forecasting, NAVENVPREDRSCHFAC Contractor Report CR 78-01.

cyclone wind probabilities and that of the Atlantic is the crux of this report and these will be described in detail.

The tropical cyclone wind probability forecasting model generates estimates of the probability of 30 and 50 knot winds occurring at a point given that the tropical cyclone occupies a particular position. The model includes many features of the strike probability model which is based on an analysis of position forecast errors to determine the probability of a tropical cyclone occupying a particular geographic position. Wind profile errors in the forecast of maximum wind and in the forecast radius of 30 and 50 knot winds are similarly analyzed to determine the 30 and 50 knot probabilities of occurrence.

Jarrell[3] (1978), in his development of the strike probability model, based the theory of strike probability on three assumptions:

1) All tropical cyclone forecasts are subject to error;
2) Difficulty of forecast and size of forecast error are related; and
3) The occurrence of errors is random and approximates a multimodal bivariate normal probability distribution.

Subsequent studies by independent investigators in three ocean basins frequented by tropical cyclones verified these assumptions. Nicklin[4] (1977), Thompson and Elsberry[5] (1979), and Crutcher[6] (1980) using data from the western Pacific, eastern Pacific and the Atlantic, respectively , also developed individual methods to group forecasts into three classes of forecast difficulty. A general relative classification evolved in each study to yield forecast error groups of below average, average, and above average errors. These groups were also referred to as Class I (easy forecasts), Class II (average forecasts) and Class III (difficult forecasts) in previous reports. Each investigator also utilized sufficient statistical data and prescribed sufficient parameters to describe the bivariate normal distributions for each of the three classes and for forecasts of 24, 48 and 72 hours.

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[4]Nicklin, D.S., 1977: A Statistical Analysis of Western Pacific Tropical Cyclone Forecast Errors, Naval Postgraduate School, M.S. Thesis, June.

[5]Thompson, W.J. and R. L. Elsberry, 1981: An Analysis of Eastern North Pacific Tropical Cyclone Forecast Errors, Monthly Weather Review, V 109, pp. 1930-1938.

[6]Crutcher, H.L., 1980: Tropical Storm Forecast Error and the Bivariate Normal Distribution. 13th Tech. Conf. on Hurricanes and Tropical Meteorology, AMS, Miami, FL.

2.0 Model Description

2.1 Basis for Utilization of Atlantic Model

Analysis of eastern Pacific tropical cyclones has been hampered by both a lack of historical data from the region and a lack of targets (land mass or ships) which would provide the necesary incentive. Therefore the wind characteristics of the eastern Pacific cyclones have not been as well studied as those of the western Pacific and the Atlantic.

A study by Upton[7] (1973) indicated that eastern Pacific tropical cyclones may be more closely related to Atlantic hurricanes than western Pacific storms in extent, intensity and other features. His value of 23.5 n mi for the radius of maximum wind for eastern Pacific cyclones would place them well within the 15-30 n mi range of Shea and Gray[8] (1972) for moderate Atlantic storms. Reports by Frank and Clark[9] (1979) and Simpson et al[10] (1968) indicate that the

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[7] Upton, T.G., 1973: An Analysis of the Thermal and Circulation Features of Eastern North Pacific Cyclones Using Aircraft Reconnaissance Data. Naval Postgraduate School, M.S. Thesis.

[8] Shea, D.J. and M.W. Gray, 1972: The Structure and Dynamics of the Hurricane's Inner Core Region. Colorado State Univ., Atmospheric Science Paper 182, Ft. Collins, CO.

[9] Frank, N.L. and G. Clark, 1979: Atlantic Tropical Systems of 1978, Monthly Weather Review, V 107, pp. 1035-1041.

[10] Simpson, R.H. et al, 1969: Atlantic Tropical Disturbances of 1968, Monthly Weather Review, V.97, pp. 240-255.

eastern North Pacific tropical cyclones may be considered a westward extension of the North Atlantic/Caribbean tropical cyclone area.

More importantly perhaps is the implication by Jarrell[11] (1981) that Classes 1, 2 and 3 group similarities (or differences) in the different ocean basins may be due in part to collection methodologies and forecast emphasis and techniques. Longer range (72 hr) forecasts are much better in the western Pacific than in the Atlantic while short range forecasts are better in the Atlantic. The western Pacific storms are forecast by the USN/USAF Joint Typhoon Warning Center located on Guam and emphasis is on long range forecasts related to military oriented operations and decision making. Atlantic hurricanes and eastern Pacific tropical cyclones are forecast by the National Weather Service whose primary interest is short range public warning forecasting. This would seem to provide further rationale to use the Atlantic model for the eastern Pacific.

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[11] Jarrell, J.D., 1981: Atlantic Strike Probability Program, NAVENVPREDRSCHFAC Contractor Report CR 81-04.

2.2 The Eastern Pacific Wind Probability Model

Tropical cyclone wind probability was developed as an extension of the western Pacific strike probability program by Jarrell[1] (1981). The concepts of the strike portion of the eastern Pacific model are similar to those developed for the western Pacific. However, the eastern Pacific model uses a discriminant analysis routine developed specifically for that region (Thompson and Elsberry[5]) and the Tsui[12] routine (used in the Atlantic wind probability model) to determine wind profiles and to handle asymmetrical storm distribution.

The eastern Pacific strike probability program used the UCLA BIOMED discriminant analysis routine (Dixon[13], 1975) to develop functions from eastern Pacific data to discriminate on forecast error. Predictands were forecast error Classes 1, 2 and 3. In contrast to western Pacific results, there was generally poor discrimination between Classes 1 and 2 (similar to Atlantic results) while Class 3 appeared to be well separated from 1 and 2 (again similar to the Atlantic results). Table 1 depicts average forecast errors for classes 1, 2 and 3 for each ocean basin.

---

[12]Tsui, T.L., 1980: Surface Wind Distribution of Western North Pacific Tropical Cyclones; 13th Tech. Conf. on Hurricanes and Tropical Meteorology; Miami, FL.

[13]Dixon, W.J., 1975: <u>BMDP Biomedical Computer Programs,</u> University of California Press, Berkeley.

TABLE 1

Average forecast errors (NM) for Class 1, 2 and 3 tropical cyclones for western Pacific (WP), eastern Pacific (EP) and North Atlantic (NA) basins.

	WP			EP			NA		
	1	2	3	1	2	3	1	2	3
24 hr	99	130	148	94	97	132	81	99	160
48 hr	204	251	286	176	188	154	200	236	325
72 hr	324	378	407	275	297	393	362	394	477

If we interprete poor discrimination as "nearly equal forecast errors for different classes", we can compare the classes for respective ocean basins. Averaging differences between Classes 1 and 2 (24, 48 and 72 hr) and then between Classes 2 and 3 for each basin, we obtain the following:

Differences:	WP	diff	EP	diff	NA
Class 1 to Class 2	44.0	31.7	12.3	16.3	28.6
Class 2 to Class 3	27.3	38.3	65.6	12.0	77.6

The average error difference (in NM) between classes can be (depicted as diff) reinforces the arguments of section 2.1; that is, the eastern Pacific classes seem more closely related to the Atlantic (either in nature or forecast emphasis) than the western Pacific.

Thus while using the unique eastern Pacific strike probability program, this model uses the wind probability derivation and concepts used in the Atlantic.

The Atlantic wind profiles and tropical cyclone asymmetry are derived using methods produced by Tsui[12]. Tsui, using wind radius data from tropical cyclone warnings over a 12-year period (1966 to 1977), determined that the profile of the tangential wind speed along the radial axis was exponential. He further determined that maximum wind and persistence could be statistically related to the size of the storm and that the asymmetric shape of the storm's wind pattern could be correlated to the forward speed of movement of the storm. A simple empirical relationship was derived to provide an estimation of any wind radii:

$$V/V_{max} = \exp(-0.693R),$$

where V is the wind speed of interest, V_{max} is the maximum wind speed of the storm, and R is a ratio of the radius associated with V to the radius associated with one-half of V_{max} (r_{half}) respectively. Asymmetrical storm configuration is accommodated in the profile by an empirical adjustment of the one-half radius, r_{half}, dependent on bearing relative to direction of motion and translation speed.

3.0 Testing the Eastern North Pacific Wind Probability Program (EPWINDP)

The methodology used in testing EPWINDP predicted values against observed values is identical to that used in the Atlantic by Jarrell[2] (1981). An array of 30 points in the eastern North Pacific was selected (figure 1). EPWINDP values for 30 and 50 knots were calculated at 12 hour intervals from the effective synoptic time of the Naval Western Oceanography Center (NWOC) forecasts for the 1980 season. Since most of these 30 points are not observing stations, actual verifying winds were not generally available. Consequently a verifying "warning time" probability greater than 50% constituted a verifying strike.

Tables 1, 2, 3 and 4 compare the expected to the observed occurrences of 30 and 50 knot winds. Predictions are associated with percentage groups of increasing width, < 1/2%, 1/2 to 1 1/2%, . . . etc. Time integrated probabilities were verified only if a continuous record was available over the entire time period.

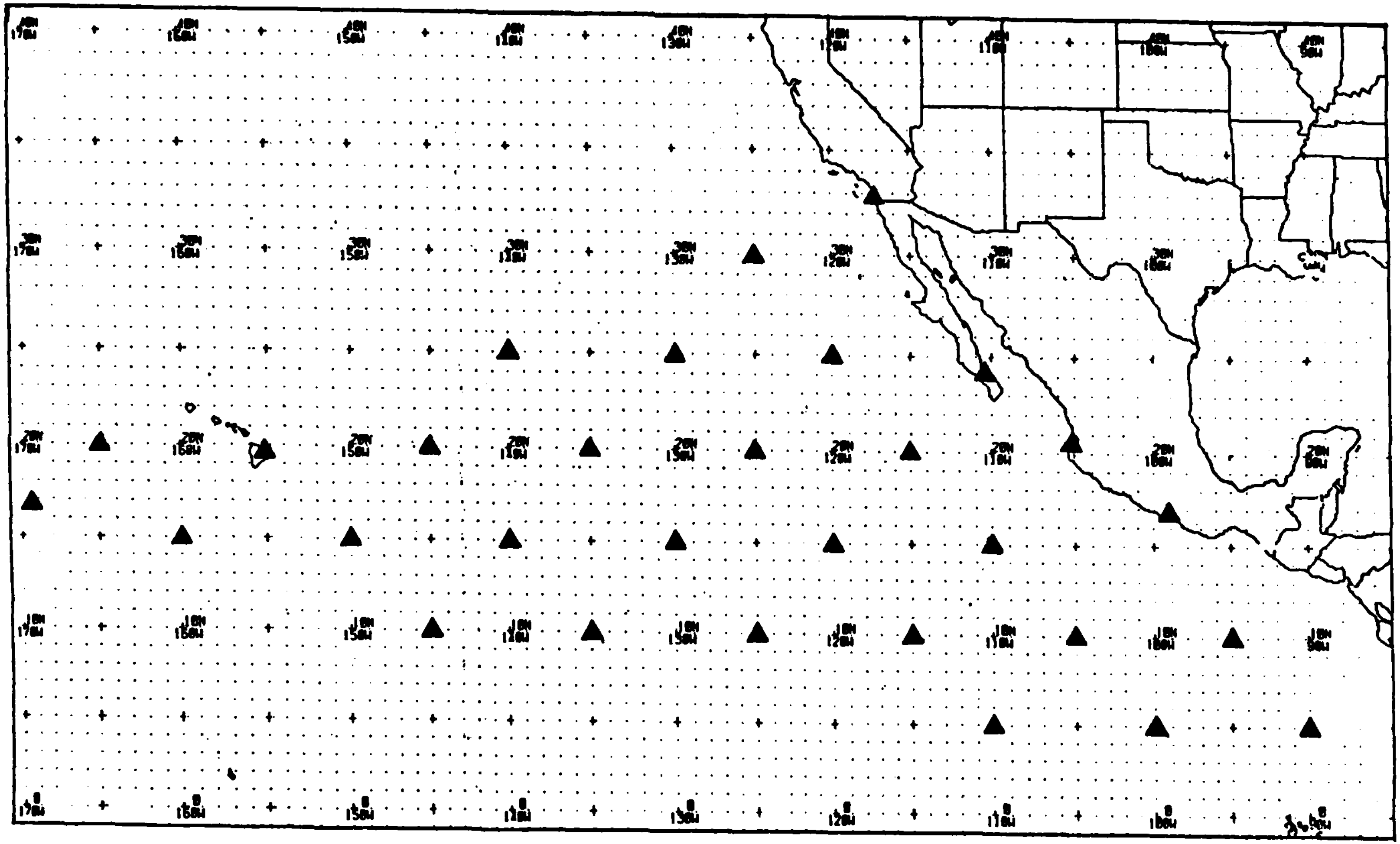

Figure 1. Selected test points (30) in the Eastern Pacific.

	50 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	5161	0	1	3937	1	2	2668	1	2
½ - 1½	101	1	2	168	1	2	187	2	1
1½ - 3½	54	1	2	84	2	1	97	2	1
3½ - 7½	42	2	2	45	2	1	37	2	1
7½ - 15½	23	3	3	26	0	3	11	1	0
15½ - 31½	13	3	1	0	0	0	0	0	0
31½ - 63½	6	2	1	0	0	0	0	0	0
> 63½	0	0	0	0	0	0	0	0	0
ALL	5400	12	12	4260	6	9	3000	8	5

Table 1. Instantaneous Probabilities.
50 kt winds - Expected versus Observed.

	30 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	4978	0	5**	3604	1	4**	2296	1	1
½ - 1½	106	1	5**	203	2	4	258	2	2
1½ - 3½	75	2	4	176	4	10*	221	5	12
3½ - 7½	80	4	8	137	7	13*	147	7	8
7½ - 15½	70	8	12	93	10	11	67	7	7
15½ - 31½	56	12	16	47	10	9	11	3	2
31½ - 63½	31	13	14	0	0	0	0	0	0
> 63½	4	3	2	0	0	0	0	0	0
ALL	5400	43	66**	4260	34	51*	3000	25	32

Table 2. Instantaneous Probabilities.
30 kt winds - Expected versus Observed

*Significant at 5% level.

**Significant at 5% level even after adjustment for interdependence.

	50 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	4695	0	0	3001	0	0	1635	0	0
½ - 1½	55	0	0	139	1	2	134	1	0
1½ - 3½	68	1	2	90	2	1	131	3	3
3½ - 7½	47	2	1	92	5	5	85	5	3
7½ - 15½	54	6	4	87	10	5	106	11	6
15½ - 31½	65	14	11	77	17	12	80	17	11
31½ - 63½	26	11	9	24	9	8	19	7	5
> 63½	0	0	0	0	0	0	0	0	0
ALL	5010	34	27	3510	44	33	2190	44	28

Table 3. Time Integrated Probabilities.
50 kt winds - Expected versus Observed.

	30 KT								
	24 Hr			48 Hr			72 Hr		
A≤P<B	N	E	O	N	E	O	N	E	O
< ½%	4450	0	4**	2729	0	2*	1409	0	1
½ - 1½	76	1	2*	140	1	2	143	1	0
1½ - 3½	63	1	2	111	3	4	103	2	1
3½ - 7½	79	4	4	125	7	8	134	7	5
7½ - 15½	93	10	10	138	15	15	164	18	18
15½ - 31½	109	24	22	145	32	38	141	30	43
31½ - 63½	106	48	54	99	43	51	80	35	39
> 63½	34	26	26	23	17	17	16	11	11
ALL	5010	114	124	3510	118	137	2190	104	118

Table 4. Time Integrated Probabilities.
30 kt winds - Expected versus Observed.

*Significant at 5% level.

**Significant at 5% level even after adjustment for interdependence.

Significance of the differences between the expected and the observed, as discussed in previous reports (Jarrell[11], 1981), is difficult to assess, but using a "t" test, agreement appears to be very good. The instantaneous probabilities show excellent correlation at all forecast lengths with minor under-forecasting at the shorter forecast times (24 and 48 hr). The time integrated probabilities displayed a slight tendency toward overforecasting for both 50 kt and 30 kt winds. The difference between the expected and observed occurrences were rarely at a significant level (see note accompanying tables) and the overall results are considered statistically sound.

4.0 Operational Products

The eastern Pacific wind probability program will be available for the same preselected points as the eastern Pacific strike program.* (The EPSTRKP program is actually integrated into the EPWINDP program.) Probabilities will be given in two modes, instantaneous and time integrated, and at 0, 12, 24, 36, 48, 60 and 72 hours after the warning time. The instantaneous probabiity will be the probability at the stated time (i.e., 12 hr) and the time integrated probability will be summed for the 0 to X hour time interval for an estimate of the probability that the event will be observed within that period of time.

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*Locations: Acapulco, Mazatlan, Puerto Vallarta, La Paz, San Diego, Hilo, Honolulu, Johnston Is., Midway Is.

The greatest source of probable error for the EPWINDP program will be erroneous input data. An internal check for unusual motion (expected to occur only 5% of the time in nature) will be made and suspect motion flagged. The user should then recheck input data for accuracy.

When the forecast track approaches a land mass, the forecaster should be aware of program bias. This should be minor for seaward approach to low coastal areas or over smaller islands. However, in other cases land influences will appear as rapid decreases in the instantaneous wind probabilities (especially 50 kt winds) near forecast landfall time. This will bias probabilities -- overstate them for inland sites and understate them for coastal sites. Time integrated probabilities will be less biased. This problem is caused by wind forecasts being influenced by track forecasts where landfall is concerned. A bad track forecast may cause a bad wind forecast. This was not accounted for either in development nor testing; hence the test results simulate expected actual operational results and some of the minor disparities between expected and observed occurrences no doubt stem from this.

5.0 Summary

The wind probability model for the eastern North Pacific is largely based on the strike probability program for the eastern North Pacific. Features of wind probability programs for the Atlantic and western North Pacific have been incorporated. All of these programs are operational or soon to be operational. There are only minor modifications to those components adapted herein. Test results of the eastern North Pacific wind probability program (EPWINDP) demonstrated excellent agreement between expected and observed results.

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